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Barkhausen effect in steels and its dependence on surface condition

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Micromagnetic Barkhausen signals from magnetic materials originate from the discontinuous changes in magnetization under the action of a changing applied magnetic field. Barkhausen emissions that are detected by a sense coil come predominantly from a surface layer. In iron based materials this layer is about 500 μm thick. The Barkhausen signal is affected by changes in material microstructure and the presence of residual stress, since these affect the dynamics of domain wall motion. The selective attenuation of high frequency components of the Barkhausen signal due to eddy currents in electrically conducting materials is used to evaluate changes in material condition at different depths inside the material. Barkhausen measurements on specimens subjected to different thermal treatment during surface conditioning procedures are presented. Also presented for comparison are analysis of the material condition using x-ray diffraction for assessment of residual stress, and microhardness measurements which evaluate the surface microstructure condition. The results show that Barkhausen emissions can be utilized to evaluate changes in the surface condition of materials. © *1997 American Institute of Physics.* [S0021-8979(97)61008-7]

I. INTRODUCTION

Surface condition plays a significant role in determining the fatigue lifetime of materials. Effective methods are needed for the assurance of desired surface conditions during component manufacture. Furthermore, evaluation of the surface condition of components while in service permits detection of material degradation and can be used to detect the onset of failure. Magnetic properties of steels are sensitive to changes in material conditions such as microstructure and the presence of residual stress. This sensitivity arises from the fact that the magnetization process in steels is largely dominated by the motion of domain walls. Defects in the microstructure such as inclusions and dislocations impede the motion of domain walls and therefore affect magnetic properties including permeability, hysteresis loss, and coercivity. Long range residual stress in the material introduces an induced anisotropy which alters the permeability values.[1]

Magnetic Barkhausen effect emissions arise from the discontinuous changes in magnetization. At low field strengths this is principally due to the motion of the domain walls. These emissions can be detected, measured, and analyzed. They are detected in the form of voltage pulses induced in a sense coil positioned close to the surface of the material.[2] The amplitude distribution of such pulses depends on the microstructure and residual stress.[3] Further, steels being electrically conducting, the frequency bandwidth of the detected Barkhausen signal is largely determined by the distance the signal traversed in the material before it was detected at the surface. High frequency signals are alternated over shorter distances than low frequency signals. Signals from deeper in the material have lower frequency components than those from closer to the surface. Thus, an analysis of the Barkhausen signal, in conjunction with control of the bandwidth of the detected signal, permits evaluation of changes in subsurface material condition.

II. EXPERIMENT

Microstructure and residual stress changes were induced in steel components by grinding under conditions that are similar to those likely to be encountered in manufacturing, but at different feed rates. Barkhausen effect measurements were conducted on these in an effort to determine whether the treatment caused changes in the Barkhausen spectra. One group of specimens was ground at 0.85 μm/s feed rate and the results from these served as the base line for reference. Three further batches of these components were ground under increasing feed rates (4.1, 8.5, and 12.7/μm/s) to induce

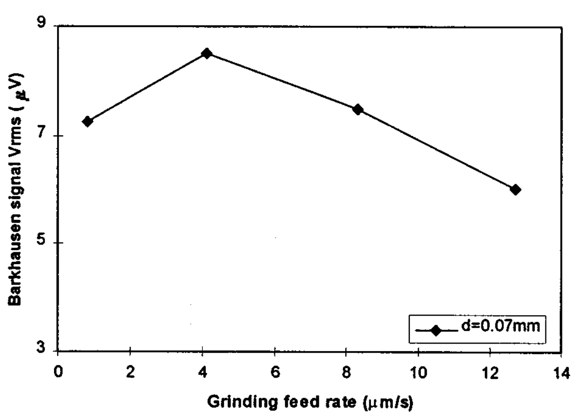

FIG. 1. Variation of Barkhausen signal, nominal depth=0.07 mm.

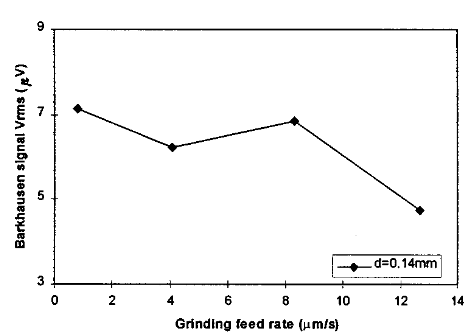

FIG. 2. Variation of Barkhausen signal, nominal depth=0.14 mm.

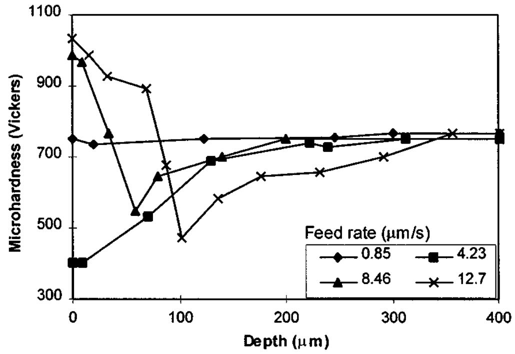

FIG. 3. Dependence of hardness on depth.

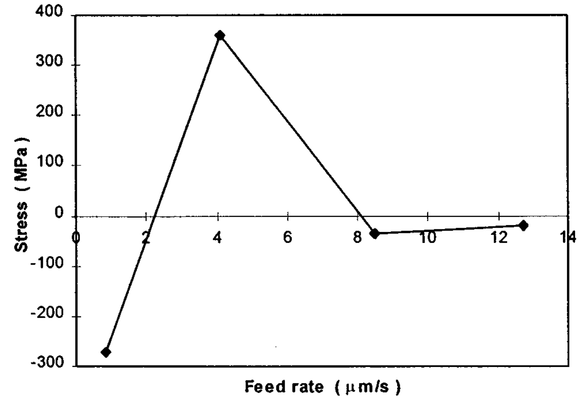

FIG. 5. Dependence of surface stress on grinding condition.

varying degrees of surface stress in the material. Barkhausen emissions were excited in the material by magnetizing it with a sinusoidal magnetic field. The Barkhausen signal was detected and analyzed at different bandwidths to estimate changes at different depths in the material. Material conditions at nominal depths of 0.07, 0.09, 0.11, and 0.14 mm were investigated by setting frequency bandwidths to 15–50, 25–75, 50–125, and 70–200 kHz. These depths were based on the classical penetration depth of electromagnetic waves in conducting media.[4] Standard material characterization techniques such as x-ray diffraction for the evaluation of residual stress and hardness measurements were used to determine properties as a function of depth.

III. RESULTS AND DISCUSSION

The root mean square value of the voltage signal detected from the specimens was analyzed and compared to those from the reference specimen. Figures 1 and 2 show the variation of the Barkhausen signal strength emanating from depths 0.07 and 0.14 mm below the surface. It was seen that, under increasing feed rates, the Barkhausen signal strength from the surface layer initially increased and then decreased. This behavior of the Barkhausen signal from a material with a positive magnetostriction coefficient such as steel, is indicative of an initial increase in tensile component in the residual stress along the direction of the applied field. At the

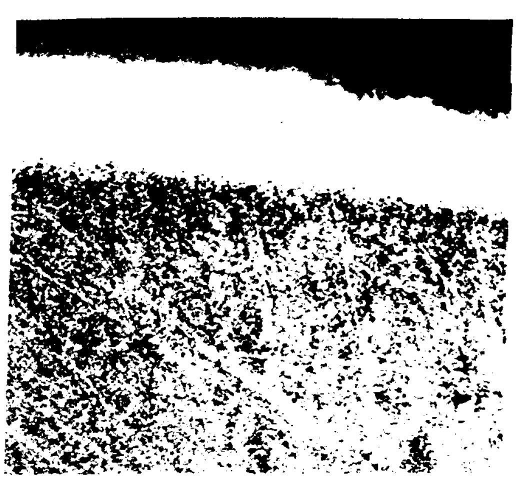

FIG. 4. Micrograph of specimen ground at 12.7 μm/s.

higher feed rates, there is a hardening of the surface layer. Barkhausen signal from deeper in the material (0.14 mm) indicates the onset of hardening only at the highest feed rates. Cross sectional hardness measurement revealed a similar pattern, typically seen in ground components.[5,6] At higher grinding rates, as the material temperature rose above the tempering temperature, a softening of the surface layer results. At very high rates, the material surface, quenched by the heat flow into the bulk and flowing coolant after being heated above the austenitizing temperature, showed the formation of a layer of martensite at the surface, as shown in Fig. 3. The martensite layer was also seen in a micrograph of a cross section of the specimen, Fig. 4. X-ray measurements of the residual stress at the surface, as shown in Fig. 5, indicated an initial decrease in compressive stress followed by an increase at the higher feed rates. This was consistent with the indications from the peak amplitude of the Barkhausen measurements.

IV. CONCLUSIONS

In steel specimens subjected to grinding, it was found that the indications of the material changes in the surface could be determined from an analysis of the Barkhausen signal. These results were compared with the results of standard techniques for the characterization of material such as hardness and x-ray diffraction. It seems from these results that the analysis of Barkhausen effect signals provides a convenient and reliable method for determining changes in the surface condition such as surface residual stress.

ACKNOWLEDGMENT

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